Influence of surface conditions on wear and friction of hardmetals and zirconia based ceramic composites

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***Abstract* –At present there is an enormous industrial demand for wear resistant materials to be used in applications such as machining tools, metal forming dies, bearings and gears. Hardmetals and ceramic composites could meet this need, as they exhibit an extremely high hardness, stiffness, wear resistance and chemical inertness. Moreover, their electrical conductivity allows them to be manufactured by electro-discharge machining (EDM), a thermal process with material removal occurring via the discharge of energy between the work piece and a tool electrode.**

Dry friction experiments were performed on a number of tungsten carbide based hardmetal grades and zirconia based ceramic composites using a small-scale pin-on-plate test rig. The tested materials were either polished, ground or EDM'ed, resulting in a different surface roughness. The observed wear was qualified by optical microscopy, scanning electron microscopy, energy dispersive X-ray analysis and X-ray diffraction analysis. Wear tracks were quantified using surface scanning topography in order to derive wear maps and develop wear models.

***Keywords* – hardmetal, zirconia, ceramic, wear, friction, reciprocate sliding, electro-discharge machining (EDM)**

I. INTRODUCTION

Electro-discharge machining (EDM) [1] is a manufacturing process that allows to create shapes in materials irrespective of their mechanical properties, provided they are electrically conductive. Hardmetals and zirconia based ceramic composites are materials that satisfy this condition. Moreover, they exhibit an excellent hardness, stiffness, wear resistance and chemical inertness. Thus, they are extremely appropriate to be used for applications such as machining tools, metal forming dies, bearings and gears, which are exposed to friction in a large degree.

The influence of polishing, grinding and several EDM-finishing regimes on the tribological behaviour of a number of tungsten carbide based hardmetal grades and zirconia based ceramic composites was investigated.

II. EXPERIMENTAL

A. Test Materials

The hardmetal grades consist of a tungsten carbide matrix, with cobalt or nickel as binder and chromium and/or vanadium as grain growth inhibitor. The zirconia based composites exhibit a zirconia matrix (40 wt% ZrO_2) with a secondary phase (60 wt% WC or $TiC_{0.5}N_{0.5}$ or TiN) and alumina (Al_2O_3) and/or yttria (Y_2O_3) as grain growth inhibitor. Their chemical, microstructural and mechanical properties are summarized in TABLE 1 and TABLE 2.

TABLE 1: Hardmetal grades: average grain size, binder mean free path length, compressive strength, Vickers hardness, indentation fracture toughness, Young's modulus, thermal conductivity.

Hardmetal grade	WC10Co	WC8Ni (Cr)	WC10Co (Cr/V)	WC6Co (Cr/V)
Grain size [µm]	2.165	0.808	0.318	0.548
BMFPL [µm]	0.926	0.296	0.136	0.166
Comp. Str. [MPa]	4200	5000	6600	7200
HV10	1149 ±10	1376±17	1685 ± 38	1913 ±13
K_{IC}^{30kg} [MPa $\sqrt{m}$]	> 20.6	15.2	11.1	9.3
E [MPa]	578 ± 6	557 ± 11	541 ± 4	609 ± 4
K [$W.m^{-1}K^{-1}$]	105	85	85	90

TABLE 2: Zirconia based ceramics: Vickers hardness, indentation fracture toughness, Young's modulus, electrical resistivity.

ZrO_2 based ceramic grade	WC [µm] 0.8Al_2O_3	TiCN [µm] 1.75Y_2O_3	TiCN[nm] 2.75 Y_2O_3	TiN [µm] 1.75 Y_2O_3
HV10	1433 ± 9	1422 ± 10	1629 ± 8	1470 ± 7
K_{IC}^{30kg} [MPa $\sqrt{m}$]	8.5 ± 0.2	7.0 ± 0.2	3.9 ± 0.1	5.6 ± 0.1
E [MPa]	340	284	307	274
ρ [Ω.m]	4.7 10^{-6}	1.7 10^{-5}	3 10^{-6}	4.6 10^{-6}

B. Test Rig

Pins were reciprocally slid against hardmetal and zirconia based ceramic counter plates using a high frequency tribometer, in accordance with ASTM G133. The highest hardness hardmetal grade, i.e. WC6Co(Cr/V), was used as pin material. The friction coefficient between pin and plate and their combined wear were measured online.

C. Test Conditions

The wear tests were performed in an air-conditioned atmosphere of 23 °C and a relative humidity of 60 %. Normal loads were varied up to 50 N, based on the laws of Hertz [2], which allow a maximum admissible normal load calculation between two sliding surfaces depending on their compressive strength. The stroke length of the reciprocating motion was 15 mm. A frequency of 10 Hz, i.e. 0.3 m/s, was applied. The test duration was associated with a sliding distance of 10 km, allowing wear amounts to be compared.

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III. RESULTS

A. *Friction and wear*

The tribocouple combinations exhibit initially a high friction coefficient and wear rate, as the contact surface between pin and plate is very limited, then they decrease, as the contact surface increases while the pin penetrates into the plate, and eventually a regime situation is reached, where friction coefficient and wear rate are almost constant.

Several influences on wear behaviour were investigated, Figure 1. It has to be noted that a relatively large scatter up to 15 % occurred between the experiments because of the powerful influence of minor factors on the type of predominating wear mechanism.

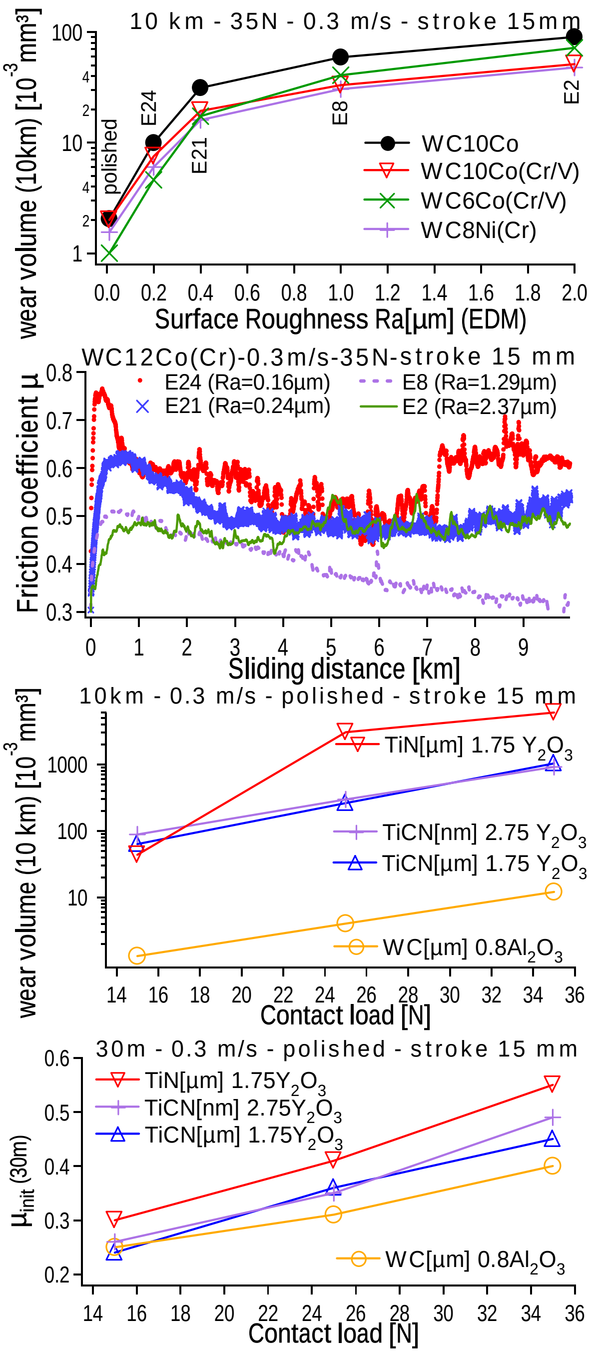

Fig. 1: wear volume and friction coefficient for hardmetal and ZrO_2-based ceramic grades against WC6Co(Cr/V) pins as function of surface roughness (a), sliding distance (b) and contact pressure (c,d)

Friction coefficient and wear are noticed to increase for an rising contact pressure, which can be attributed to a stronger adhesion of the two sliding surfaces. Moreover, they increase and decrease respectively with increasing EDM finishing. An optimal tribological situation, i.e. low friction coefficient and wear, is found with the WC8Ni(Cr) grade for the hardmetals, and with WC grade for the zirconia based ceramics.

B. *Post-mortem analysis*

The generated wear of plates and pins was measured by surface scanning topography and analyzed by SEM, Figure 2. Amongst the observed wear phenomena are: polishing of the wear track surface, formation of wear debris, rounding and/or pull-out of tungsten carbide grains as well as larger chunks, the formation of an adhering layer in the wear track, binder modification due to oxidation and heating [3,4].

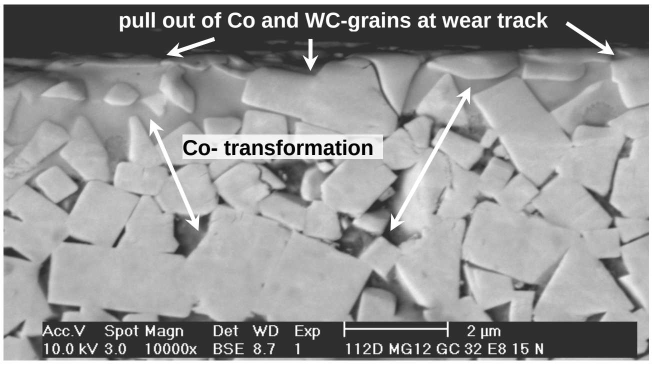

Fig. 2: Cross-sectional view at wear track of EDM'ed WC10Co hardmetal (SEM)

IV. CONCLUSIONS

Dry friction experiments on polished, ground and EDM'ed hardmetals and zirconia based ceramics reveal that their wear occurs according to two main mechanisms: abrasion and adhesion. Their wear and friction coefficient are noticed to decrease and increase respectively with decreasing roughness due to surface finishing. A rising contact pressure increases their friction and wear. The significant influence of the binder material in the hardmetals and the secondary phase in the zirconia based ceramics was proven. Correlations between microstructural, mechanical, tribological and surface properties are further investigated for material optimalization.

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